AN APPLICATION OF SIMULATION TO THE IMPROVEMENT OF FORK TRUCK OPERATIONS

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Summary

Most manufacturing operations assign fork trucks to the individual shop units which need them. This can lead to excessive numbers of fork trucks and low average utilization. The pooling of fork truck resources under a central authority can resolve this problem. Fewer trucks are needed in operations with fork truck pools to provide an equivalent level of service. The purpose of this report is to document the results of a simulation study of the operation of a fork truck pool in a mass manufacturing operation and to demonstrate the practicality of such a plan.

The Fork Truck Problem

An audit of Room Air Conditioning Department's manufacturing operation found too many idle fork trucks and a low average utilization. The recommendation of the audit team was to reduce the fork truck force. At the time of this recommendation, however, the Unit Managers of Shop Operations were requesting the purchase of four additional fork trucks and there was one rented fork truck in service. This was the paradox facing the Manager of Manufacturing and the circumstances which precipitated the present study.

A quick review of the operation substantiated the contentions of the manufacturing audit team: 1) too many fork trucks, 2) too many drivers, 3) too much "dead heading" and "joy riding" and 4) the rental of fork trucks when actually there were more trucks on hand than needed.

Alternatives

The following alternatives were investigated in our efforts to uncover a plan which would raise fork truck utilization and provide more efficient and effective service to Shop Operations.

A. Complete Pooling of Fork Trucks (Radio-Dispatched)

Under this proposal, all fork truck services would be acquired from a central pool. To request a fork truck, the foreman would telephone a central dispatcher. The dispatcher would then relay the need via two-way radio to the fork truck driver. The fork trucks would not return to a central location after every move. They would remain in the area where their last job was completed until another call is received.

B. Partial Pooling of Fork Trucks (Radio-Dispatched)

This plan is basically the same as Plan A above except that some fork trucks would be pooled while others would be retained as captives. A captive fork truck is a fork truck designated for the sole use of a specific shop unit. As such, it will not be called upon to service other shop units when it is temporarily idle. Readiness to serve the designated shop unit is judged to be of primary importance.

C. Reassignment of Work Responsibility

There was very little basis under the present operating conditions for the present assignment of fork trucks. As the plant grew, fork trucks were assigned to the shop units with the most need. Under the present operating conditions, it seems reasonable to consider an improved assignment plan for fork trucks as an alternative.

After reviewing these alternatives very carefully, the decision was made to investigate Plan B further.

Proposal: Partial Pooling of Fork Truck Services

To implement this system, it is necessary to install a transmitter and receiver in a central dispatcher's office along with the necessary telephone instruments. Two-way radios are installed on each fork truck. Because of the work load, it is anticipated that both a dispatcher and an answer clerk will be needed to operate the system. Incoming telephone calls for fork truck service will be received by the answer clerk. It will be the clerk's responsibility to mark the requestor's information on an EAM card and then pass it to the dispatcher. It will be the responsibility of the requester to tag the pallet or pallets to be moved with a specially designed form to be provided.

Not all fork trucks will be assigned to the pool operation. Certain fork trucks will be designated captives. Reasons for assigning captives include: special driver skill requirements, high present utilization and potentially expensive shutdown if waiting time for fork truck services were excessive. Designation as captive is not permanent. The number of trucks to be designated as captives will fluctuate with changes in operating conditions. Control over captive fork trucks is retained by the central fork truck operation at all times.

Under this proposal, there will be a greater reliance on low-cost material handling equipment. Fork trucks will be used for heavy and/or long distance moving. Lighter and/or shorter moves will be accomplished with walkers and jackstackers. The fork trucks will be used basically to deliver from column to column while walkers and jackstackers will be used to shuffle loads in and out of storage.

"It Sounds Good, But Will It Work?"

The workability of a centralized fork truck pool is evidenced by the success of a similar plan at another General Electric Operating Department. This other department has successfully operated a centrally-dispatched fork truck system for 10 years now. With the plan fully implemented, they were able to eliminate 33 fork trucks and 33 drivers. This brought their total fork trucks from 125 to 92 while reducing the number of drivers from 103 to 70.

With this information, management became more receptive to the proposal but they were not completely convinced. The other Operating Department mentioned above is a job shop operation while Room Air Conditioning Department is a mass manufacturing operation. To provide stronger evidence of the proposal's workability, a simulation study was initiated. It must be evident by now that management was very concerned with the successful operation of the proposed fork truck pool. Implementation without prior knowledge of the systems operating characteristics could obviously shut down the entire manufacturing operation.

Data Collection

The fork trucks of Room Air Conditioning Department have been sampled several times before the present study. The results are shown in Figure 1. Previous studies did not produce the information necessary to provide inputs to a simulation. Therefore, a special study to provide inputs for the simulation was required.

Year	Avg. Fork Truck Utilization	Work Study Performed by
1966	59%	Methods and Time Standards
1970 (May)	52%	Mfg. Audit Team
1970 (Oct.)	57%	Mfg. Engineering

Figure 1. Results of Several Fork Truck Studies

Data necessary to perform the simulation study included the arrival rate of demand for fork truck service and the distribution of times to process a call. Standard work sampling plans would not permit us to collect the necessary data. A standard work sampling plan calls for going to a designated spot and noting the activity or inactivity of the subject. To acquire the information needed, it was obviously necessary to observe the subject for an interval of time. The interval chosen was one hour. There was a concern that this procedure would introduce bias into the study, but there appeared to be no alternative. With the results in hand, it appears that the procedure actually introduced very little bias. Note in Figure 1 that there is only an absolute difference of 5 percent in the two 1970 studies. This difference is no greater than could be accounted for by sampling variation.

The decision was made to work sample only the first shift fork truck operation. The rationale was that the work load was heaviest on first shift. If a fork truck pool could operate under first shift conditions, it could easily operate under second and third shift operations.

Since it was desired to simulate the operation of an entire shift, it was necessary to collect eight hours of data on each truck. The data collection is lengthy and represents a significant percent of the total study time. The number of days to collect all the necessary data can be found by dividing the number of fork trucks to be studied by the number of men applied to the data collection task.

Work Sample Results

Actual utilization of fork trucks was compiled from the study data and is presented in Figure 2.

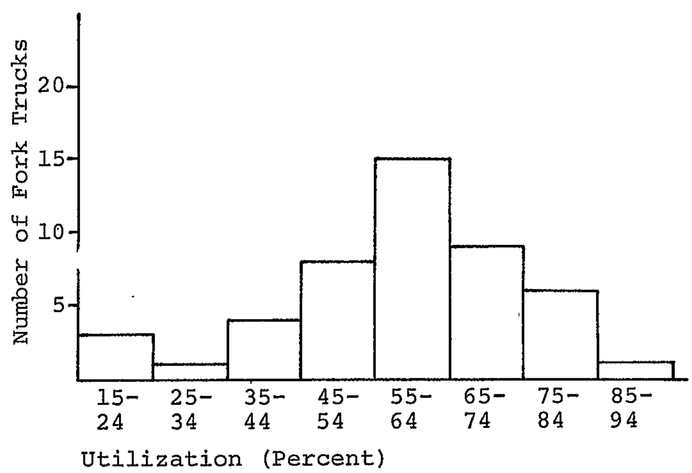

Figure 2. Work Sample Results

Room Air Conditioning Departments Average actual utilization of fork trucks is 57%.

Simulation Language

This proposal was first programmed by the author two years earlier in General Electric Time-Sharing BASIC for a similar study at another, not previously mentioned, Operating Department. The BASIC program used equal time increment simulation and was very inefficient. So much time was spent programming that little time was left for model refinement and experimentation.

The proposal was reprogrammed in GESIM for the present study. GESIM is essentially GPSSIII with minor modifications to run on GE(now Honeywell) 600 series computer. Programming required much less effort than the original work and several refinements were added. Among the refinements added was that service time was made a function of fork truck capacity. It was noticed that the fork truck work in the fabrication area was different from the work being performed in the assembly area and that basically the heavy capacity fork truck served the fabrication area while the light capacity fork trucks served the assembly area. After a statistical test was made of the hypothesis, this refinement was added to the model. Without the significantly shorter programming time, we most likely would not have had the time to give this consideration

The GESIM simulation provided more information than the BASIC simulation. The BASIC simulation was programmed to provide information on averages and maximum values. With the GESIM TABLES and QTABLES, the entire frequency distributions were obtained. In general, GESIM fulfilled the purpose of a simulation language; it provided routines that were common to many simulation problems. For example, it was necessary to program in detail a routine to maintain the queue discipline for the BASIC simulation. In GESIM, it was only necessary to specify a QUEUE/DEPART complementary black pair.

Modelling the Proposal

Certain tradeoffs in model complexity and effort/expense had to be made. This simulation model was built to provide information on only one element of the total waiting time. This element is time awaiting availability of a fork truck. The total waiting time that a foreman would see under the new system is the sum of the following four elements:

1. Time to walk to a phone

   This element was not used to judge the performance of the system since on an incremental comparison with the present system, this time would negate the time now being spent by the foreman trying to find his fork truck.

2. Time to place the phone call

   The time to tell the answer clerk the necessary dispatch information was studied during our visit to the other Operating Department with a fork truck pool implemented. The time was approximately 0.5 minutes.

3. Time awaiting fork truck availability

   This element was the most difficult to predict and thus became the principal subject of the simulation model.

4. Time for fork truck to travel to requesters site from the location where the last job was completed.

   The maximum travel time was determined by timing an actual trip of a fork truck from one corner of the building on a diagonal to the opposite corner; it took 3 minutes. The minimum time for this activity was assumed to be 0.5 minutes.

A given mix of fork truck capacities was available based upon the fork trucks presently owned. It was obviously judicious to pick as many high capacity fork trucks as possible for service in the fork truck pool. A 2000# fork truck can only service calls for 2000# capacity work, whereas a 6000# fork truck can service calls for jobs requiring 2000#-6000# capacity. It was reasoned that it is better to refrain from committing a 6000# fork truck to a job calling for a 2000# fork truck when there are a limited number of 6000# fork trucks. The service discipline used was one in which a fork truck of capacity K as it becomes available will be dispatched to a job requiring capacity K. If there are no jobs requiring this capacity, an attempt will be made to assign the fork truck a job requiring K-1000 capacity and on down until it has searched the entire job list. An important assumption here is that a high capacity fork truck can service all jobs requiring less capacity. In actual practice, the larger size of high capacity fork trucks may hinder their maneuverability in tight work spaces and thus limit their usefulness for certain jobs.

As stated earlier, certain fork trucks would be retained as captives. Nineteen fork trucks were retained as captives because there was either special driver requirements, high present utilization or potentially expensive shutdown if waiting time for fork truck service became excessive. Since there were 49 fork trucks, that means that a pool would have to service an area previously served by 30 fork trucks. It was decided to explore the effects of operating the pool with 16-20 fork trucks in the pool.

Based upon fork trucks available for service, the following mix of fork truck capacities was used in the simulation experiments:

Capacity	Number
2000#	6-10
3000#	3
4000#	4
5000#	1
6000#	2

The above situation could best be described as semi-restricted availability. A 4000# fork truck can do 2000-4000# work, but it cannot do work requiring 4001-6000# capacity. To evaluate the effects of semi-restricted availability on the system performance measures, a second model was built to study a fork truck pool with unrestricted availability; i.e., all 6000# fork trucks.

Assumptions About the Proposed System

To insure the success of the proposal, it is extremely important to be able to anticipate factors that will cause the actual system to deviate from the mode of operation projected by the simulation model. Deviations will be caused by two factors: 1) differences in the present operating conditions (used as simulation inputs) and future operating conditions and 2) the inclusion of incorrect assumptions in the model. Anticipated changes in operating conditions were studied, but none was found with any significance to the operation of a fork truck pool. The following assumptions were made:

1. Fork truck drivers and the production force take their lunch and breaks at the same time.

2. Fork truck driver will always be able to locate the job. During our visit to the operating department with a fork truck pool implemented, we noted that this assumption was not completely valid. Under the proposed system, the requester would always be notified when a job cannot be located.

3. Fork truck drivers call in immediately upon the completion of a move.

4. Fork trucks will be continuously available in an operational state; i.e., fork trucks cannot break down and drivers are always available.

Experimentation

The simulations were run with one time unit equal to one minute. To bring the model to steady state, the simulation was run for one quarter of a day and reset before statistical measurements commenced. The primary performance measures for the simulation were:

1. Average fork truck utilization.

2. Percent of customers with zero waiting time.

3. Average waiting time for all customers.

4. Average waiting time for those customers who experienced a delay.

5. Maximum waiting time experienced by any customer.

A total of 10 runs were made. Computer runs were differentiated by the following two factors:

FACTOR A: Availability
- A1: Semi-Restricted
- A2: Unrestricted

FACTOR B: Number of fork trucks in pool
- B1: 16 fork trucks
- B2: 17 fork trucks
- B3: 18 fork trucks
- B4: 19 fork trucks
- B5: 20 fork trucks

All ten simulations were run for a full shift (460 time units) after initialization. A total of 1578 jobs attempted to get fork truck services in each simulation run. Each run cost about ten dollars. Run time on the GE (now Honeywell) 600 series computer was 0.75 minutes for a simulated day, or a 766: 1 ratio of real time to computer time. The use of GPSS user chains improved run times and also made the modelling of certain system features much easier.

Results

The results of the ten runs were surprising; there was no difference in the results of the model with semi-restricted availability and the model with unrestricted availability. Since there was no difference in these two modes of operation, the results can be displayed with the five graphs in Figures 4-8.

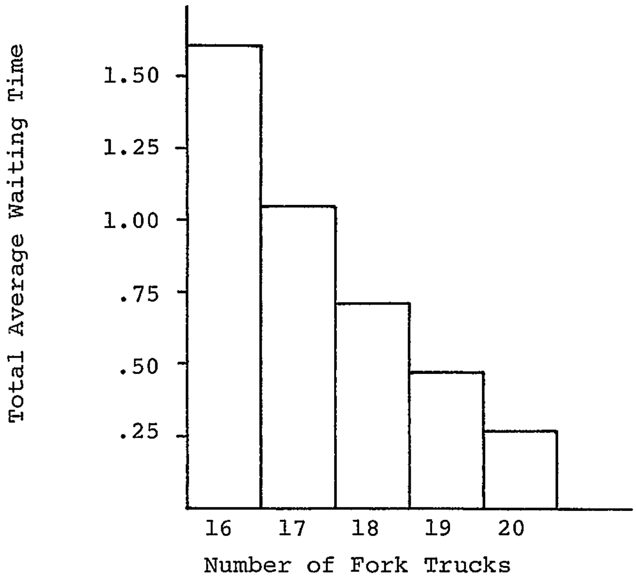

Figure 4. Plot of Total Average Waiting -vs- Number of Fork Trucks in Pool

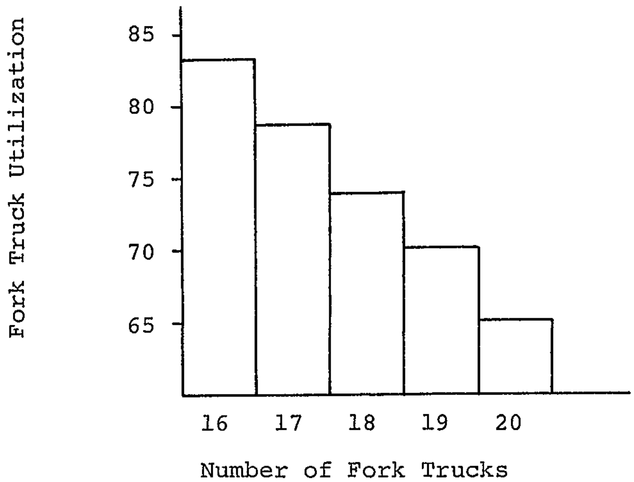

Figure 5. Plot of Fork Truck Utilization -vs- Number of Fork Trucks in Pool

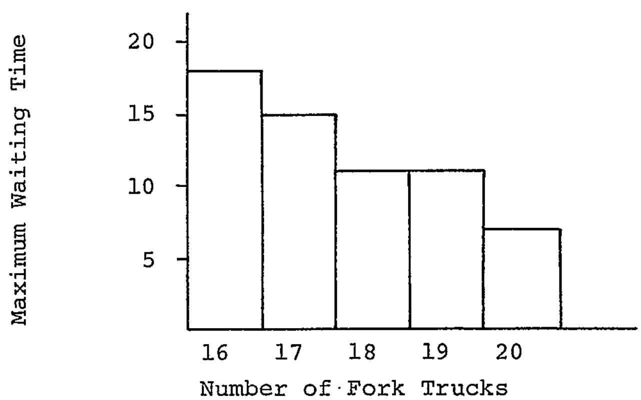

Figure 6. Plot of Maximum Waiting Time -vs- Number of Fork Trucks in Pool

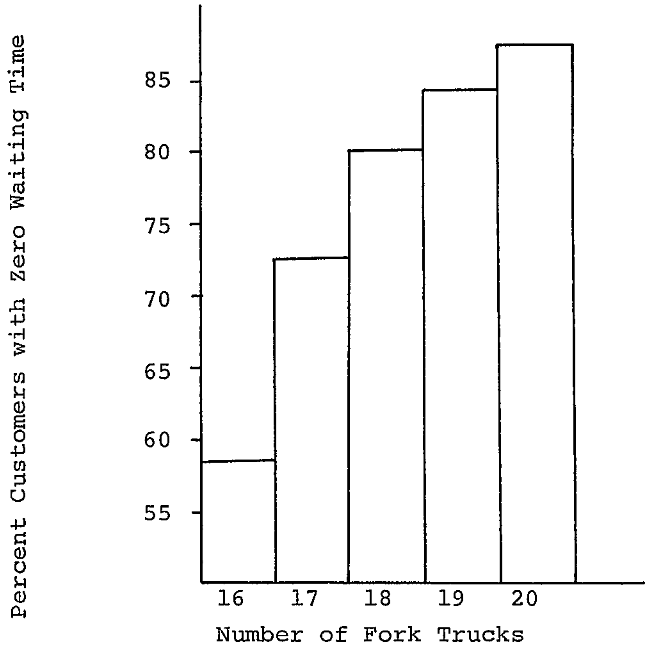

Figure 7. Plot of Percent Customers with Zero Waiting Time -vs- Number of Fork Trucks in Pool.

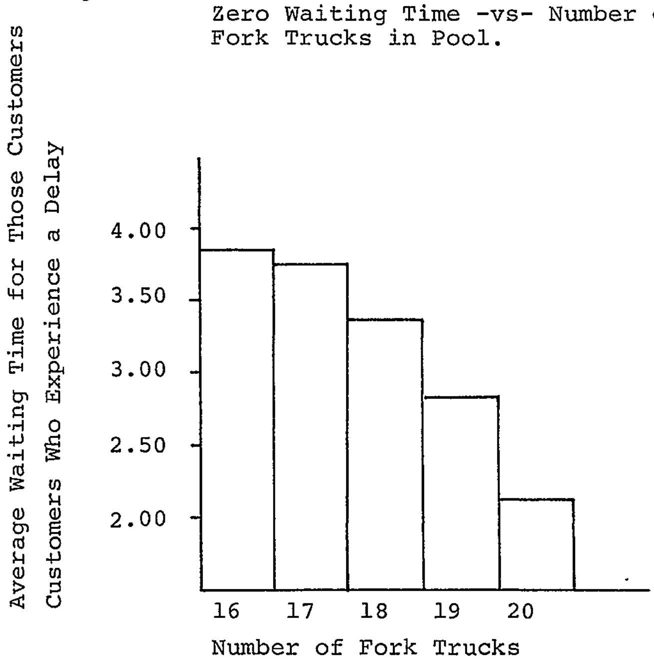

Figure 8. Plot of Average Waiting Time for Those Customers Who Experienced a Delay -vs- Number of Fork Trucks in Pool

Statistical Validation

The two-sample Kolmogorov-Smirnov test was used to examine the capability of the model to reproduce statistical distributions of actual conditions. Both the capacity distribution and the process times were validated. The results are shown in Figure 9.

Distribution	Max Observed Diff.	K-S Critical Diff.	Conclusion
Capacity	.006	.049	Not Significant
2000# Proc. Time	.012	.057	Not Significant
3000# Proc. Time	.035	.131	Not Significant
4000# Proc. Time	.040	.155	Not Significant
5000# Proc. Time	.109	.319	Not Significant
6000# Proc. Time	.126	.357	Not Significant

Figure 9. Results of Kolmogorov-Smirnov Test

The null hypothesis is that the two samples (simulation results and actual results) came from the same population. The tests were performed at the 5 percent significance level.

The Kolmogorov-Smirnov test was picked for validating the simulation results because of its sensitivity to any kind of differences in the distributions from which the two samples were drawn. It will respond to differences in location (central tendency), dispersion and skewness.

Conclusion

Based on the results of the simulation study, the following conclusions are offered:

1. Using only 6000# fork trucks for pool service will not improve the service offered by a pool with a capacity mix roughly proportional to the distribution of capacity calls.

2. The service discipline used can have a very significant impact on the distribution of waiting time and other system performance measures. Further work on this project should center around a study of additional service disciplines.

3. An effective technique used in the presentation of this proposal to management was to outline system weaknesses as well as strengths. For instances, we were able to anticipate management's concern for a radio failure which would shut down the entire manufacturing operation. Two standby modes of operation were presented and the project was saved from what might have been a quick death. This example plus the anticipation of several other difficult circumstances spelled success for the project.

4. The last, and obviously most important conclusion is that a fork truck in a mass manufacturing environment is a workable scheme. In the present study, the results indicated that the one rental fork truck could be eliminated, the four requests to purchase additional fork trucks were unnecessary and the regular fork truck force could be reduced from 48 to 36-38 by implementing a partial fork truck pool.